P1.24: X-Rays Microdetectors Based on an Array of Scintillators: A Maskless Process Using Laser Ablation

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Abstract

*This paper describes a X-rays microdetector based on an array of wells filled with scintillator crystals. A thick-film of aluminum (*500 μm*) is etched by Laser Ablation Technique (LAT) in order to achieve a square well with side of* 100 μm *and* 490 μm *deep vertical sidewalls. The aluminum thick-film was chosen because it is a good reflector in the visible range and for improving the number of photons collected by each photodetector. Also, the cross-talk between adjacent wells is reduced. As first approach, for a 4x4 wells array prototype, LAT is an inexpensive process when compared with Deep Reactive Ion Etching (DRIE) and avoids the need of etching masks. In this system the X-ray energy is first converted to visible light by the scintillator. This light is then detected by a photodetector fabricated in a standard CMOS process.*

Keywords

Scintillator, Digital Radiology, X-ray, Laser Ablation

INTRODUCTION

Several medical imaging methods, such as computed tomography, ultrasound and magnetic resonance imaging are digital, while conventional X-ray imaging remains an analog technique [1]. X-ray imaging techniques usually have very strict exposure requirements due to the narrow brightness depth of the radiography films. They also offer very few possibilities of image processing. Digital radiography systems offer the possibility of imaging with a wider range of exposure requirements and provide an image that may be processed and displayed in a variety of ways.

The advantages of digital radiographic systems may be divided into three classes:

- Dose reduction,
- image processing and display in real time, and
- flexibility in image storage and retrieval.

The first advantage of digital radiography is the possibility of dose reduction. In conventional radiology, the dose is determined by the sensitivity of the image receptor and the film brightness depth. In digital radiology, both these constrains can be relaxed. Dose reduction can be achieved by adjusting the dose to give the required signal to noise ratio in the image. Further reductions are possible by using the x-ray spectrum that gives the lowest dose for a given signal to noise ratio and by recovering any losses in contrast using digital techniques.

The second advantage of digital radiology is the possibility of changing the characteristics of the image during the medical evaluation. The way of mapping the image in levels of brightness on a screen can be completely controlled by the user.

The third advantage of digital radiology is the possibility of image storing in a computer database and or transmission of the images to long distances.

This paper presents an array of x-rays microdetectors based on a aluminum foil with cavities filled with powder scintillator. The Laser Ablation Techniques (LAT)allows to open the cavities without an etching mask.

SYSTEM DESIGN

In medical imaging diagnosis, the X-rays are produced with voltages from 25 kV to 120 kV, approximately. These voltages produce an intensity peak ranging from 10 keV to 100 keV. A standard silicon wafer (525 μm thick) only absorbs about 2.2% of the 100 keV X-rays energy, not being suitable for the making of X-rays sensors. Therefore, a x-ray scintillation layer is necessary to convert X-rays into visible light, which is then converted to an electric signal by means of an array of photodiodes[2]. Each scintillator is isolated from its neighbors by the high-reflective inner-walls of the well which allow multiple reflections and guides all produced light to the photodiodes. Moreover, introducing a reflective layer above the scintillator (in the X-rays path) confines the light inside the wells for increasing the efficiency.

Therefore, the device consists of many micromachined aluminum wells, where the scintillator is deposited. This structure is bonded on the silicon die, which contains the pho-

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todetectors and readout electronics (Fig. 1).

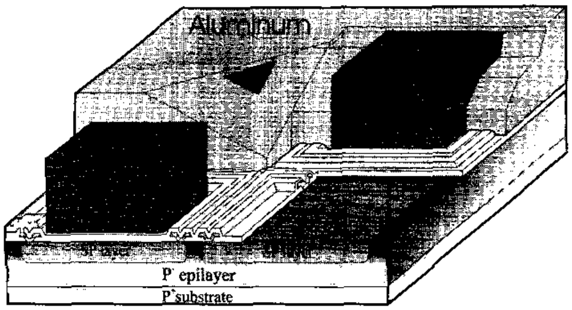

Figure 1. Sensor structure.

Figure 2 shows the probability of the x-rays energy be transmitted by the 10 μm aluminum layer above the scintillator. It is possible to see that almost all energy near 1.5 keV is absorbed. This corresponds to the k edge of the aluminum whose energy is 1.55960 keV. At the same graphic is possible to see that at 10 keV, 93.3% of the energy is transmitted, and at 20 keV, the percentage is 99.1%. With these values one can conclude that the 10 μm aluminum above the scintillator is suitable for sensors measuring x-rays in the range from 10 keV to 100 keV.

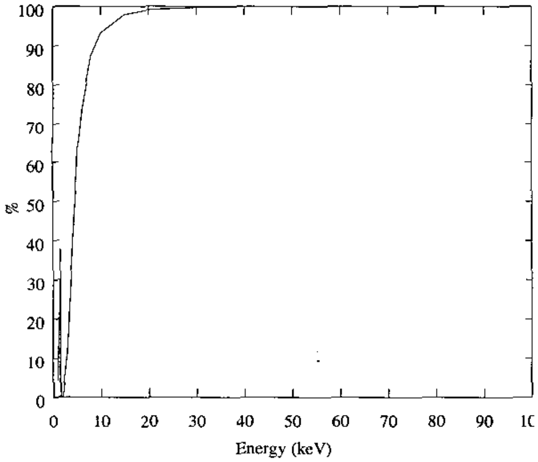

Figure 2. Transmittance of the 10 μm aluminum layer above the scintillator.

Figure 3 shows the probability of the energy be absorbed by the 490 μm of Gd_2O_2S:Pr,Ce,F scintillator. This scintillator is good for energies below 30 keV, and above 60 keV. Both energy ranges are interesting in medical applications: below 30 keV for breast imaging, and above 60 keV for dental radiography. Once again, the effect of the k edge of the Gadolinium at 50.2391 keV can be seen in the same figure. The produced light of the Gd_2O_2S:Pr,Ce,F scintillator is near 40 000 photons for each 1 MeV of absorbed x-rays [3]. The final result, considering the aluminum transmission (figure 2), the scintillator absorption (figure 3), and the conversion factor of 40 000 photons/MeV, can be seen in the graph of figure 4.

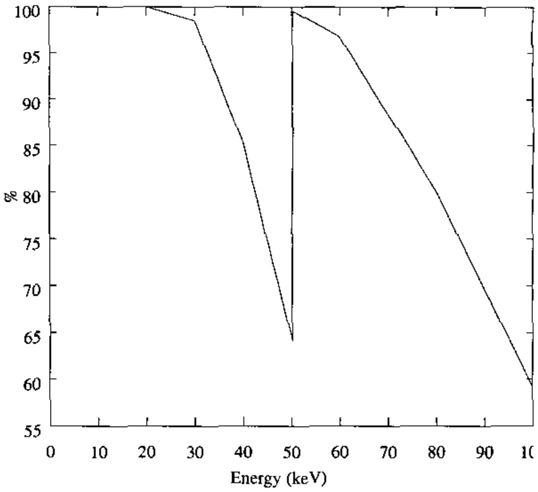

Figure 3. Absorption of the 490 μm scintillator (Gd_2O_2S:Pr,Ce,F).

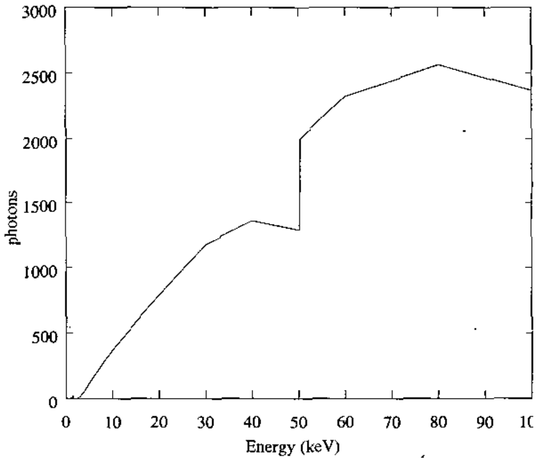

Figure 4. Number of visible photons detected by an ideal photodiode for each x-ray photon that reaches the sensor.

LASER ABLATION APPARATUS

The use of LAT in micromachining technology became very important in film technology as it allows selected etching and selected deposition of films with high precision. LAT have an inherent advantage of cleanliness and simplicity over laser-assisted methods of processing materials. Almost all kinds of material can be processed; metals, semiconductors, polymers and high-Tc Superconductors. Excimer laser ablation has been used to replace conventional wet chemical lithography for the fabrication of films, which typically have dimensions in the tens of microns. In the traditional lithographic process, a material is exposed with a mask pattern; subsequent wet chemical etching causes exposed areas to be dissolved, forming the desired structure. In contrast, with excimer ablation lithography, material to be removed is directly ablated, eliminating at least additional time-consuming steps for each removalr process [6]. The progress in the development of photoresist materials make it possible to use shorter wavelengths of optical radiation.

Lasers are also used in the aid packaging of integrated-circuit devices. Three laser-based micromachining processes - material excision in flexible circuit manufacturing, soldering, and via drilling - have replaced traditional machining methods in the manufacture of integrated circuits. These techniques also can be used in the packaging stage. Chip-scale packages are used primarily in products in which portability requires small size and very dense interconnects.

Figure 5 shows the laser ablation setup of our laboratory. This setup is composed by an excimer KrF laser MINex (Lambda Physik) working in pulsed rating at 248 nm with pulse energy of 30 mJ and peak power of 2 mW, optical mirror and lenses for focusing of the laser beam, translation table with the sample and controlling system [4]. The translation table has an absolute accuracy of 3.6 μm and repeatability of 0.9 μm [5]. For adjusting the optical system a HeNe laser has been used.

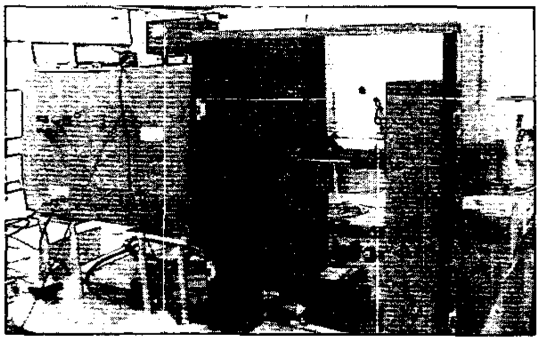

Figure 5. Laser ablation setup.

FABRICATION

Laser Ablation Techniques (LAT) have been used to open cavities in the thick-film of aluminum. The main problem for doing 490 μm deep cavities with perfectly vertical side walls by LAT is the focusing of the laser beam. By focusing the beam at the surface of the aluminum film, the bottom of the cavity is not focused. In order to minimize the problem, a plano convex lens with a focal distance of 250 mm and an iris of 10 mm diameter have been used (figure 6).

With a laser beam of 10 mm diameter, focused at the surface of the aluminum film, the beam thickness at 490 μm is close to 20 μm. With some patience, focusing the laser beam at the middle of the aluminum film thickness, the error is near 10 μm, which is acceptable for the present work.

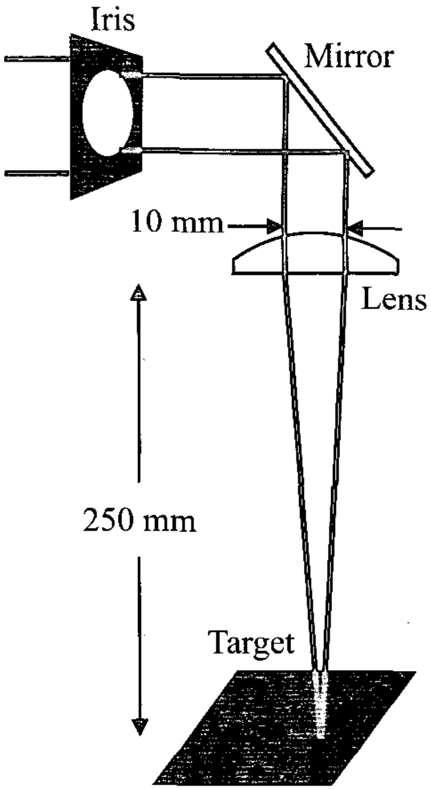

Figure 6. Optical setup of the laser.

The cavities are filled by a clamping pressure, with a powder scintillation phosphor (Gd_2O_2S:Pr,Ce,F) in a low-temperature vacuum chamber. Figure 7 shows the aluminum cavities filled with the scintillator.

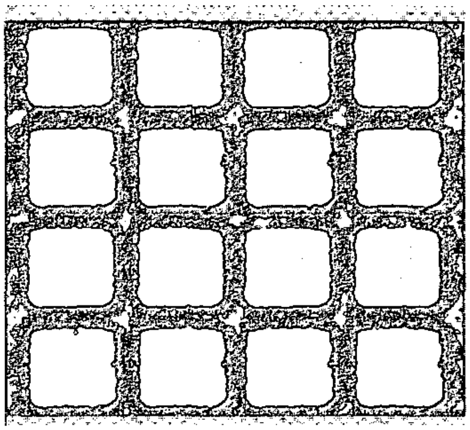

Figure 7. Photo of the aluminum wells

The reflectivity of the aluminum inner-walls of the wells are poorly affected by the LAT etching.

CONCLUSIONS

X-rays microdetectors based on a 4x4 square well array of scintillators have been designed and prepared. A maskless process based on LAT reveals itself more suitable for opening deep trenches in thick films for prototyping when compared with DRIE techniques. This array of microdetectors offer the possibility for X-ray imaging with flexible exposure requirements and provides images that may be processed and displayed in several forms. As future work we are trying hexagonal-well shape in order to increase the fill factor.

ACKNOWLEDGMENTS

This work was supported by The Foundation of Science and Technology, Portugal, FCT-CTM/POCTI/33751/1999; Grant-BD SFRH/BD/1296/2000.

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